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Snow-Compaction Equipment Snow Drags

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109

Technical Report

SNOW-COMPACTION EQUIPMENT

SNOW DRAGS

Y-F015-11-078

Type C
Final Report

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by

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U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

NCEL REPORTS ON SNOW-COMPACTION EQUIPMENT AND TECHNIQUES
(Scheduled)

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OBJECT OF TASK

To develop drags suitable for leveling and finishing compacted-snow areas constructed by Navy cold-processing snow-compaction techniques.

ABSTRACT

Numerous types and sizes of drags were tested and evaluated during the development of the Navy's snow-compaction techniques. As techniques were developed for constructing skiways, roads and runways on shallow and deep snow fields, two types of drags, along with other special equipment, were found necessary to produce good-quality compacted snow.

A snow-leveling drag was needed in the preliminary stages of construction to level and compact windrows left by other equipment, to spread and level shallow drift and light snowfall, and to remove slight surface irregularities. A two-element, 925-pound wooden drag with metal cutting edges was developed for this work. This simple drag was effective at speeds up to 500 feet per minute and could perform light leveling on compacted snow areas at a rate of 5.3 acres per hour. The drag was useful also in maintenance of compacted-snow areas and in leveling and spreading new snow and drift around polar camps. Based on 1959 prices, the approximate cost of this drag is $500 per unit.

A snow-finishing drag was needed in the final stage of construction to obtain a hard, smooth finish on compacted snow. Such a finish was necessary for successful operation of aircraft, cars, trucks and other wheeled vehicles on the compacted surface. A two-element, 2,830-pound steel drag with cylindrical bottoms was developed for this work. At a speed of 350 feet per minute, this drag could produce a good-quality finish on 5.3 acres of compacted snow in an hour provided the working elements, or skids, were penetrating 1 to 2 inches into the surface. The drag was useful also in compressively compacting and finishing new snowfalls and drift on compacted-snow areas and around polar camps. Based on 1959 prices, the approximate cost of this drag is $1,500 per unit.

CONTENTS

INTRODUCTION

Ice caps in the arctic and antarctic are perennial snow fields; most land and sea areas in these regions are also covered with light to moderate snow pack during the fall, winter and spring. Techniques and equipment to utilize this snow as a building material for emergency and temporary roads, runways and skiways could materially improve year-around operations in these regions.

The feasibility of producing static and dynamic load-bearing snow was first investigated by the Navy in the antarctic during 1947 on Operation Highjump. In the intervening years, cold-processing snow-compaction techniques have been developed that will produce high-strength snow capable of supporting vehicles and aircraft on both annual and perennial snow fields. Basic compaction equipment to produce load-bearing snow are a machine to pulverize and intermix, or depth-process, the natural snow, and a large roller to compressively compact the pulverized mass. Other equipment needed for snow compaction are drags, planers, finishers and sprayers.

This report covers the development and selection of drags for leveling and finishing snow-compacted areas. The development, authorized by the Bureau of Yards and Docks under Task Y-F015-11-078, was made by the U. S. Naval Civil Engineering Laboratory, Port Hueneme, California. Compaction techniques and other special snow construction equipment are described in the series of Laboratory reports on Snow Compaction listed on page iii.

Two types of drags are necessary for constructing and maintaining compacted snow. One, called a leveling drag, is needed in the preliminary stages of construction to obtain a level working surface. The other, called a finishing drag, is needed in the final stage to obtain a smooth surface. Both are needed to maintain compacted-snow areas and both have limited use in general maintenance of snow around polar camps.

HISTORICAL BACKGROUND

In February 1947 during Operation Highjump,[1] a snow airstrip was constructed on the Ross Shelf Ice, Antarctica, near Little America IV. The technique used for its construction was relatively simple. The sastrugi, or snow ridges on the surface formed by the wind, was rough-graded with a Canadian-type snow drag; then the graded area was compressively compacted with a tractor and a pontoon drag. In addition to its compactive effort, the pontoon drag produced a fairly smooth level surface.

The Canadian-type snow drag[2] was developed by the Royal Canadian Air Force during World War II for airfield maintenance. It consisted of adjustable steel blades, which could be raised or lowered, mounted on wooden runners. The pontoon drag consisted of two T7 and two T6 Navy pontoons fitted with a chain tow bridle (Figure 1). For the Highjump airstrip construction, the pontoon drag was weighted with 2 tons of pierced plank for a gross weight of 7 tons and a bearing pressure of 0.88 psi.

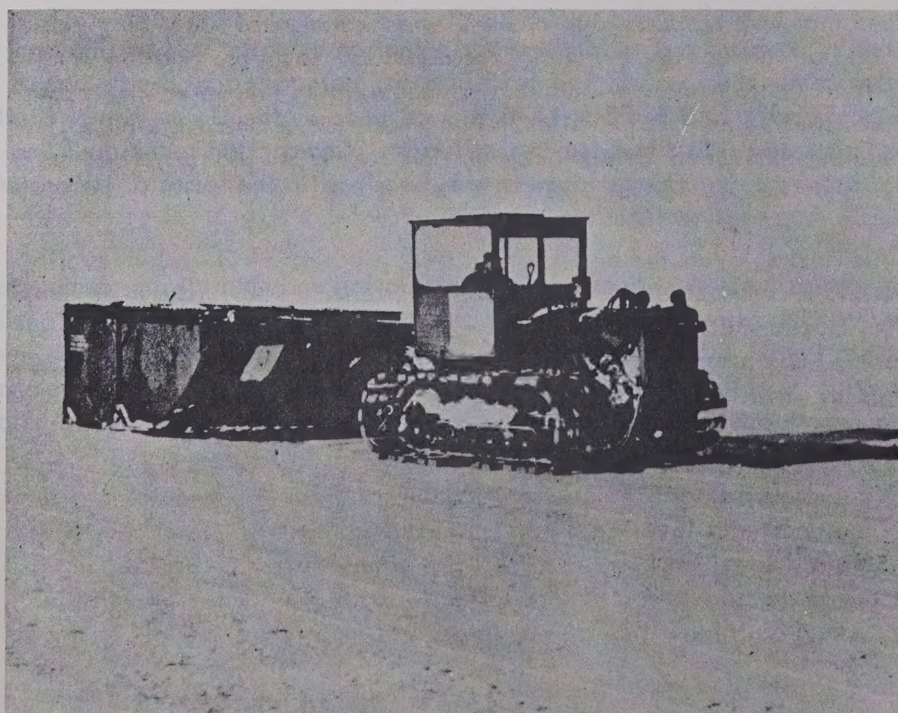

Figure 1. Finishing the airstrip at Little America IV in 1947 with the 7-ton 2 x 2 pontoon drag.

With a minimum of maintenance, the Highjump airstrip was satisfactory for repeated operation of R4D aircraft on skis during February 1947. Near the end of February, it was tested with an R4D on wheels. Numerous wheel breakthroughs occurred in the compacted-snow mat during this test. They were attributed to non-uniformity of strength and an inadequate depth of compaction.

The report[1] on the Highjump airstrip served as a basis for the research task on snow compaction. Study of the mechanical properties of snow, coupled with the development of techniques and equipment for its compaction, was continued until 1959. During this period, field trials were conducted at sites in Colorado,[3] Alaska,[4] California,[5] and Greenland.[6,7] Some of the compaction equipment also saw limited use in the antarctic during Operations Deep Freeze I and II[8] and in the 1959 Squaw Valley trials.[9,10] A resume of these trials is given in Appendix A.

SNOW-LEVELING DRAG

In the field trials (Appendix A) it was found that a fairly level working surface was necessary during construction for uniform strength in compacted snow. Initial leveling and primary compaction of large areas were obtained with a snowplane and a large steel roller. Subsequent leveling and primary compaction of windrows left by other equipment and of shallow drift, light snowfall and slight surface irregularities were accomplished with a drag. A two-element wooden drag with metal cutting edges was developed for these light leveling jobs.

Criteria. Kragelski,[11] from a series of experiments in Russia during WW II, found that floats, or drags, with small contact areas were more effective than rollers for initial compaction of soft, low-density snow. He also found that, within limits, there was no advantage to heavy floats; as the smaller the area of contact and the smaller the bearing pressure, the more effective the float. These findings were confirmed in Navy tests of various types of drags,[3,4,5] and the following criteria were developed for the design of a snow-leveling drag:

1. The drag, made of timber, was to consist of two working elements, or screeds, rigidly connected by a frame.

2. Each screed was to have a flat bottom.

3. The total area of contact for the screeds and the total weight of the drag was to be kept low consistent with simple rugged construction.

4. Each screed was to be fitted with metal cutting edges.

5. The drag was to be of maximum width and length consistent with ease of tow and maneuverability, using a simple flexible towing bridle.

6. Knockdown construction was to be used to achieve minimum cubage for air transportation.

7. Simple connectors were to be used for easy field assembly.

Design. The snow-leveling drag in its final design is detailed in Y&D Drawing No. 813537, dated 1 September 1959. The experimental model used at Camp Hale, Colorado (Figure 2) was constructed of rough select quarter-sawed oak. Subsequent models were constructed both of oak and of select rough-sawed Douglas fir structural post and timber. In field tests, drags made of both types of wood proved equally satisfactory, and Douglas fir was accepted as a satisfactory substitute for the oak used in the early models.

Figure 2. Testing the experimental metal-faced wooden leveling drag at Camp Hale in 1950.

As designed, the total weight of the Douglas fir drag is 925 pounds, the total contact area of the screeds is 12 square feet, and the bearing pressure exerted by the drag is 0.54 psi.

Description. The drag (Figure 3) is 12 feet wide and 8 feet long. It consists of front and rear timber screeds rigidly joined by three perpendicular and two diagonal timbers. Both screeds are made of 6-inch by 6-inch rough-sawed timbers faced with 4-inch by 4-inch by 3/8-inch steel angles attached by bolts (Figure 4). The connecting members are made of 4-inch by 4-inch rough-sawed timbers. They are bolted to the screeds through clip angles and gusset plates. All assembly bolts are five-eighths of an inch in diameter for ease of handling when wearing gloves.

For single tow, a close-link chain bridle of 1/2-inch-diameter steel links (Figure 3) is attached to the front screed with 5/8-inch-diameter shackles and 3/4-inch-diameter eyebolts. Each leg of the bridle is 5 feet long and the two legs are joined with a 4-inch-diameter towing ring. The drag is painted International Orange for easy recognition in snow.

Packaging. For shipment by any type of carrier the drag is disassembled and packaged into a single bundle, as shown in Figure 5. The screeds and connecting members are banded together and the chain bridle, clip angles, gusset plates and bolts are packaged in a wooden box, which is banded to the screeds. The entire package is 12 feet long, 1 foot 6 inches wide, and 1 foot 3 inches high. Its cube is 22.5 cubic feet and its weight is 950 pounds.

1959 Costs. Three leveling drags were fabricated of Douglas fir in the fall of 1959. The total cost of the drags, including the materials, labor and overhead, was $1,384 for an average of $461 per drag.

Performance. An experimental model of the snow-leveling drag was tested at Camp Hale[3] to determine its effectiveness in spreading, leveling and compacting soft, low-density snow. Additional tests were made in the Sierras of California and in Greenland to evaluate its use in the construction and maintenance of compacted-snow areas.

The drag was found to be highly maneuverable in all types of snow. It was easy to turn and it tracked without slip on side slopes with grades up to 10 percent. The towing bridle could be attached or disconnected from the tractor drawbar by one man. Often during the trials the tractor operator performed this job unassisted.

The drawbars on the snow tractors used in the Hard Top trials[7] were about 9 inches higher than the towing eyes on the drag. This difference in height coupled

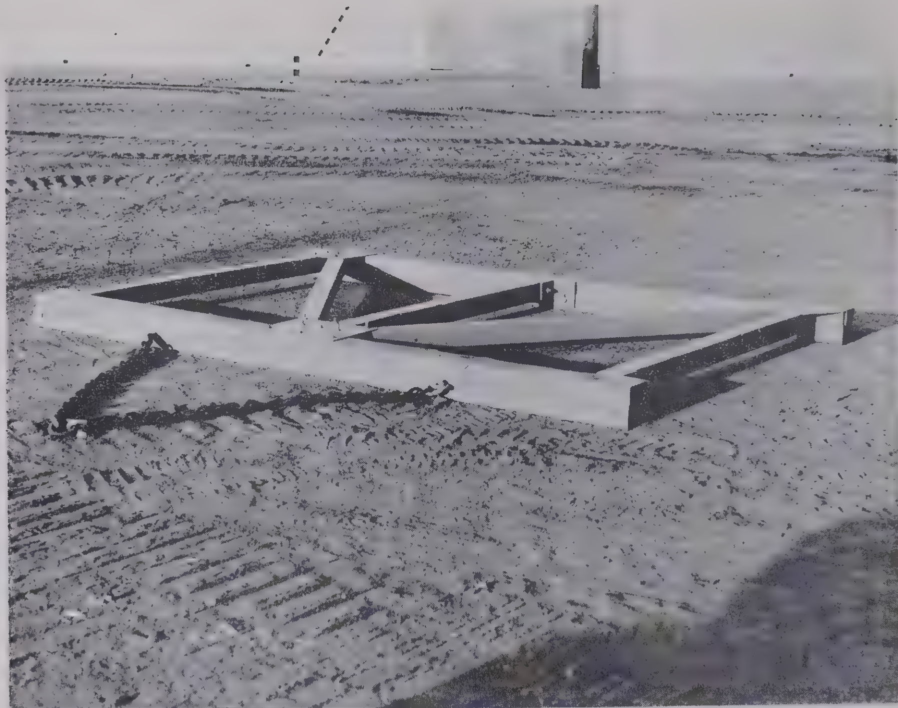

Figure 3. The prototype snow-leveling drag built for Operation Deep Freeze I in 1955.

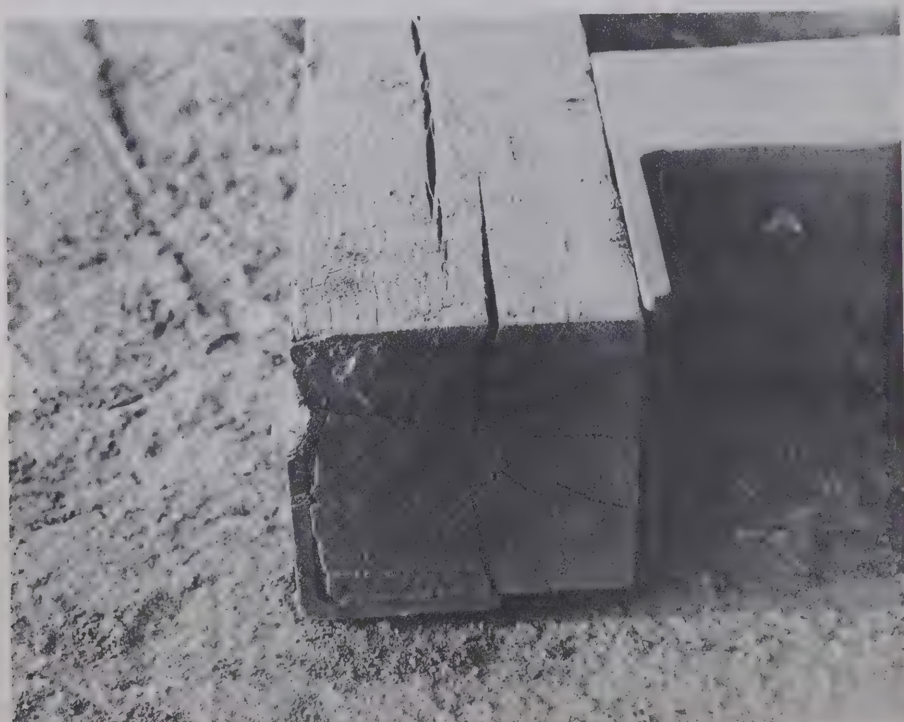

Figure 4. Detail of front screed on the wooden leveling drag, showing the metal angle cutting edge.

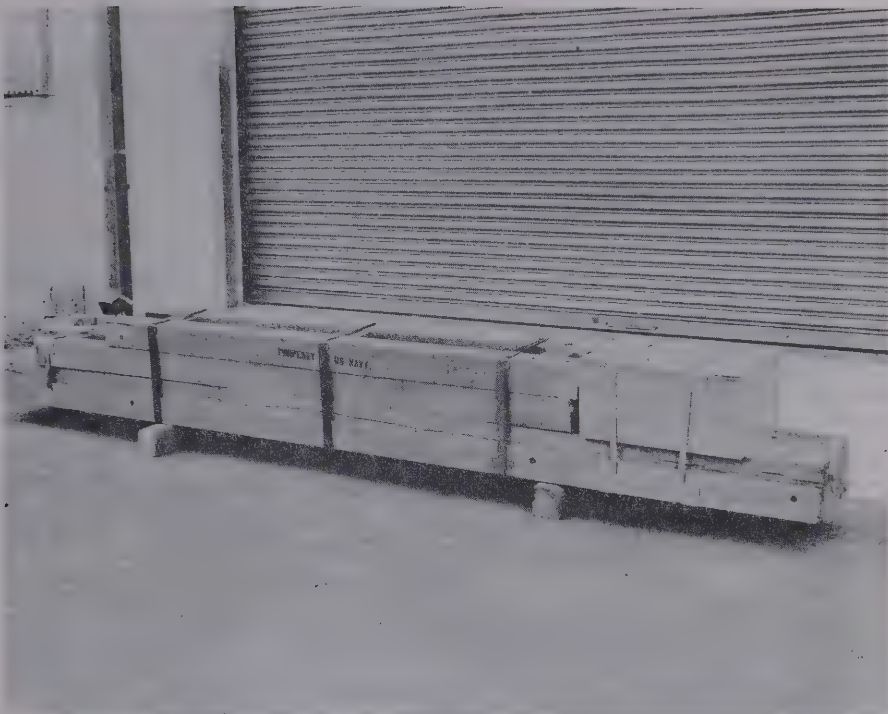

Figure 5. Snow-leveling drag packed for shipment.

with the relatively short towing bridle resulted in sufficient uplift on the drag to make both screeds effective working elements (Figure 2). In temperatures down to -50 F, the bridle withstood pulls required to break free and move the drag in all types of snow. During 1956 at McMurdo Sound, Antarctica,[8] in temperatures near -60 F, several bridles were broken when attempting to move drags after overnight parking. Following this, drags were freed with a dozer blade. Once free, the drags were used to level snow in near -60 F temperatures without breaking the tow bridles.

When not in use, the leveling and finishing drags were easily covered with new snowfall and heavy drift. For recovery after storms on the Greenland Ice Cap,[6,7] the drags were marked on opposite corners with small flags attached to 3-foot wooden stakes. This simple precaution prevented loss by burial numerous times.

The speed of dragging and the number of passes over the same area were found to be dependent upon the work being performed and the type and source of snow.

For example, two or three passes of the drag were usually required to level shallow finger drifts of snow. The first pass, made perpendicularly to the drift at about 150 feet per minute, was followed by one or two diagonal passes at about 500 fpm. This pattern of dragging not only leveled the drifts but also quickly spread the new snow laterally over the compacted area.

Windrows formed by the snowplane and snow mixer were usually spread and leveled (Figure 6) with ease in a single pass at about 350 fpm. Occasionally, diagonal dragging with a second pass at about 500 fpm was required to evenly spread this snow. The average speed of dragging for all types of work was established as 350 fpm; with an overlap of 2 feet between adjacent lanes of the drag, the average surface coverage was established as 5.3 acres per hour.

Occasionally, slight undulations and minor rough spots occurred in the surface of compacted snow subjected to traffic. Usually these irregularities could be removed with a single pass of the leveling drag at about 350 fpm. This pass not only leveled

Figure 6. Spreading windrows with the leveling drag on the Greenland Ice Cap in 1953.

the snow surface but also resulted in primary compaction of the displaced snow. For restoration of the surface hardness, or strength, additional passes with the snow-finishing drag were necessary. A combination of passes with the leveling and finishing drags was also effective in compacting new snowfalls, provided the compacted depth of the new snow was 3 inches or less and the moisture content of the new snow and the ambient temperatures were suitable for successful compressive compaction.

SNOW-FINISHING DRAG

In the field trials (Appendix A) it was found that a hard, smooth finish was necessary on compacted snow for long life and successful operation of wheeled aircraft and vehicles. Compacted snow runways built in the early trials were given patterned finishes for easy recognition from the air. Such finishes were quickly damaged, and eventually test runways were built with smooth finishes. A float, called a snow-finishing drag, was developed to produce this finish.

Criteria. In Operation Hard Top I,[6] the first compacted-snow runway built on the Greenland Ice Cap was finished with a large roller faced with corrugated metal which formed corrugations in the surface 1 inch deep by 4-2/3 inches wide. The corrugations aided in locating the runway from the air, but they were soon destroyed by solar radiation and by aircraft testing the runway. This left the surface soft and unusable. To continue testing, an experimental two-element float with cylindrical bottoms was fabricated at the site from oil drums and a wooden leveling drag (Figure 7). The smooth finish produced by this float (Figure 8) had good wearing qualities, and tests showed that it was much harder than the corrugated finish.

The compacting action of this 3,000-pound experimental float with its curvilinear working elements was similar to that of a roller, as previously shown by Kragelski.[11] On the test runway, however, this action was limited to the top 1 to 3 inches of relatively soft snow. This resulted in good spreading of the snow by the front element of the float and good finishing and compacting by the rear element. These findings resulted in the development of the following criteria for the design of a snow-finishing drag:

1. The drag was to consist of two working elements, or skids, rigidly connected by a frame.

2. Each skid was to have a cylindrical bottom with a radius of 24 inches.

3. The total weight of the drag was to be between 2,500 and 3,000 pounds.

Figure 7. Fabricating an experimental finishing drag on the Greenland Ice Cap in 1953.

Figure 8. Using the experimental finishing drag to surface the taxiway built on the Greenland Ice Cap in 1953.

4. The drag was to be of maximum width and length consistent with ease of tow and maneuverability, using a simple flexible towing bridle.

5. Provisions were to be made for gang towing.

6. Knockdown construction was to be used to achieve minimum cubage for air transportation.

7. Simple connectors were to be used for easy field assembly.

Design. The snow-finishing drag in its final design is detailed in Y & D Drawing No. 813538, dated 1 September 1959. The two-skid drag is made of steel and weighs 2,830 pounds. Each skid is 12 feet long and its bottom has a 24-inch radius of curvature.

The bearing pressure developed by the drag varies with the penetration of the skids into the snow (see Appendix B). Typical bearing pressures under the rear skid for various snow surface conditions are:

Hardness Index (R)*	Depth of Skid (in.)	Bearing Pressure (psi)
20 - 25	3	1.15
45 - 50	2	1.41
90 - 100	1	2.00
190 - 200	1/2	2.84
250 - 300	1/4	2.84

The angle between surface of the snow and the leading edge of the skid, called the bow angle, varies with the penetration of the skids into the snow. Typical bow angles for various snow surface conditions are:

*R is a relative index of hardness in snow obtained with a Rammsonde rod.

Snow Surface	Hardness Index (R)*	Depth of Skid (in.)	Bow Angle (degree)
Icy	500+	0	0
Extra hard	250 - 300	1/4	8
Hard	190 - 200	1/2	12
Fairly hard	90 - 100	1	17
Soft	45 - 50	2	24
Very soft	20 - 25	3	30

Description. The snow-finishing drag (Figure 9) is 12 feet wide and 7 feet 6 inches long. The entire unit is made of structural steel angles, channel and plate. It consists of front and rear skids rigidly joined by three perpendicular and two diagonal members. Each skid is 12 feet long, 2 feet 9-3/8 inches wide, and 8 inches high. The 24-inch-diameter cylindrical bottom of each skid is made of 3/8-inch plate. To join the two skids, longitudinal 6-inch by 6-inch by 3/8-inch angles are bolted to the skids. One is located on the leading edge of the front skid and the other is located on the trailing edge of the rear skid. The perpendicular and diagonal 4-inch by 4-inch by 3/8-inch connecting angles are bolted to the longitudinal members with gusset plates. All assembly bolts are five-eighths of an inch in diameter for ease of assembly while wearing gloves.

For single tow, a close-link chain bridle of 3/4-inch-diameter steel links is pinned to pad eyes on the longitudinal angle of the front skid. Each leg of the bridle is 5 feet long and the two legs are joined with a 6-inch-diameter towing ring. For gang tow (Figure 10) 5-foot-long boxed channel extensions are bolted to each end of the longitudinal angle on the trailing edge of the rear skid. The ends of these extensions are braced to the frame of the drag with 3/4-inch-diameter tie-rods. Towing pad eyes are located on the end of each extension. The drag is painted International Orange for easy recognition in snow.

*R is a relative index of hardness in snow obtained with a Rammsonde rod.

Figure 9. The prototype snow-finishing drag with extensions, built for Operation Deep Freeze I in 1955.

Figure 10. Prototype snow-finishing drags hooked up for three-gang tow.

Packaging. For shipment by any type of carrier the drag is disassembled and packaged into a single bundle, as shown in Figure 11. The chain bridle, gusset plates and bolts are boxed, and this box together with the perpendicular and diagonal joining members are placed in the front skid. The rear skid is then placed upside down on the front skid and the two are banded together. Wooden blocks are placed under the front skid to stabilize the package and permit handling with a fork lift.

The package is 12 feet 1 inch long, 2 feet 11 inches wide, and 2 feet 4 inches high. Its cube is 82.2 cubic feet and its weight, including the wooden box and blocking, is 2,870 pounds. This weight does not include extensions and tie-rods for multiple tow.

1959 Costs. Two finishing drags were fabricated in the fall of 1959. The total cost of the drags, including the materials, labor and overhead, was $2,770.00 for an average of $1,385.00 per drag.

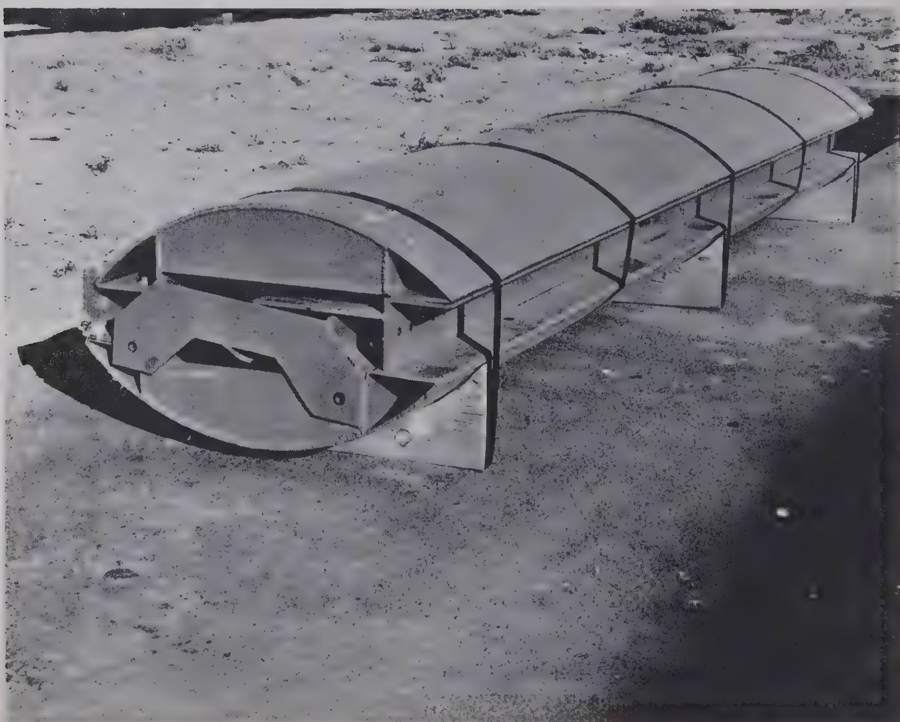

Figure 11. Snow-finishing drag packaged for shipment.

Performance. An experimental model of the snow-finishing drag was tested at Hard Top [6,7] to determine its effectiveness in producing a smooth finish on compacted snow. Additional tests were made in the Sierras of California and in the antaractic to evaluate its performance and use in the construction and maintenance of compacted snow areas.

The finishing drag, like the leveling drag, was very maneuverable when towed as a single unit behind a low-ground-pressure snow tractor. In multiple tow (Figure 10), all three drags tracked properly in straight runs, but on turns long sweeps were necessary to prevent overrunning. One man with a tractor could easily hook up a drag for single tow and with some manipulation he could hook up three drags for multiple tow. Two men could do this job with ease.

The towing bridles on the finishing drags, like those on the leveling drags, were adequate for breaking free and moving the drag in all types of snow in temperatures down to -50 Fahrenheit. Below this temperature, the bridle was subject to breakage if used alone to break the drag free after prolonged parking; [8] but once under way, the bridle was adequate for towing the drag in temperatures approaching -60 Fahrenheit.

The drawbars on the snow tractors used in the trials [7] were about an inch higher than the towing eyes on the finishing drag. This slight difference in height did not affect the finishing characteristics of the drag nor did it appreciably change the bow angle between the leading edges of the skids and the snow being finished. As shown under Design, the bow angle varied with penetration of the skid bottoms into the snow. Under good finishing conditions, where the surface was soft to fairly hard and skid penetration was between 1 and 2 inches, the finishing action of the drag was excellent. It moved easily over the surface and left a smooth, even finish (Figure 8). In very soft snow where skid penetration approached 3 inches, the action of the drag was poor. Snow would collect ahead of the front skid until a large slab of snow was being pushed forward by the drag. Eventually the drag would ride up over this slab and leave a hump in the surface. Klein, [12] in tests on aircraft skis in Canada, found that this occurred when the angle between the leading edge of the ski and the snow, or bow angle, exceeded 25 degrees.

The speed of finishing and the number of passes were found to be dependent upon the condition of the snow. The average speed of finishing for all types of snow surfaces was established as 350 fpm; with an overlap of 2 feet between adjacent lanes of the drag, the average surface coverage was established as 5.3 acres per hour.

To finish a snow surface constructed by depth-processing usually required two passes of the finishing drag. If the finish was applied while the surface was still soft enough to permit the drag to work the top 1 to 2 inches of snow, a smooth finish was always obtained (Figure 8). If finishing was delayed until the surface was hard enough to prevent the drag from working more than the top inch of snow, all tractor grouser marks and other blemishes (Figure 12) were not removed regardless of the number of passes with the finishing drag. Under these conditions, it became necessary to make a 2-inch-deep cut with the snow mixer to obtain sufficient loose snow for a good surface finish.

A two-pass finish with 1 to 2 hours between passes not only produced a smoother finish but also a harder surface than that obtained with a smooth-faced roller. By rolling, the hardness index in the top 6 inches of compacted snow averaged about 6 times that of the adjacent natural snow; with the finishing drag,

Figure 12. Smoothing surface of snow road with finishing drag during Squaw Valley Trials in 1958.

this hardness index was increased to about 12 times that of natural snow. A hardness index 24 times that of natural snow was obtained in the top 6 inches of a compacted snow mat built during Hard Top II. [7] This was accomplished by rolling the already hard snow with a 9-ton rubber-tired roller and smoothing the surface with the finishing drag.

Hardness of compacted snow is dependent upon several variables: the geographical location, the season of the year, the type and condition of the snow, the ambient and snow temperatures, and the length of the age-hardening period. The variables and their effect on the hardness of compacted snow together with typical indexes for specific conditions are contained in the report on snow-compaction techniques listed on page iii.

In addition to finishing newly compacted snow, the leveling and finishing drags were often used to compact new light snowfalls and soft drift on compacted areas. This combination of dragging was successful provided the compacted depth of the new snow was 3 inches or less and the moisture content of the snow and the ambient temperatures were suitable for producing high-strength snow by compressive compaction. The leveling drag was used first to level and initially compact the snow. Then, when the newly compacted snow was strong enough to support the finishing drag, usually 1 to 4 hours later, that drag was used to further compact the new snow layer and finish the surface.

The finishing drag was used with the large steel roller and the rubber-tired roller to compressively compact new snowfalls that could be compacted to depths not exceeding 6 inches. Successful compressive compaction of this depth of snow on top of previously compacted snow was dependent upon the moisture content of the new snow and the ambient temperatures after compaction.

The finishing drag and leveling drag were effective in spreading and compacting new snow and drift around camps at the arctic test sites. Once leveled and compacted, usage improved the hardness of this snow regardless of its initial moisture content.

CONCLUSIONS

The snow-leveling drag and the snow-finishing drag are necessary pieces of equipment for construction and maintenance of compacted-snow areas using the Navy cold-processing techniques.

1. The 925-pound Douglas fir snow-leveling drag is needed to maintain level working surfaces for other compaction equipment.

   a. It is useful in maintaining light snowfalls and soft drift on compacted snow areas and around polar camps.

   b. It is highly maneuverable in all types of snow and can be used without difficulty in temperatures down to -50 Fahrenheit.

   c. It is effective at speeds up to 500 fpm and will easily cover up to 5.3 acres per hour under good operating conditions.

   d. It is easily disassembled and packaged for shipment by any type of carrier, and it can be assembled under adverse field conditions without difficulty and hardship.

   e. It is designed for construction in small fabricating shops; based on 1959 prices, it should cost about $500 for a single unit.

   f. It is adequately detailed in Y & D Drawing 813537 dated 1 September 1959 and sufficiently described in this report for preparation of procurement documents.

2. The 2,830-pound steel finishing drag is needed to produce hard, smooth finishes on compacted-snow areas.

   a. It is useful in maintaining snowfalls and drift on compacted-snow areas and around polar camps.

   b. It is very maneuverable in all types of snow but is most effective as a finisher when the skids penetrate 1 to 2 inches into the surface.

   c. It is effective at a speed of 350 fpm and will easily cover up to 5.3 acres per hour under good finishing conditions.

   d. It is easily disassembled and packaged for shipment by any type of carrier, and it can be assembled under adverse field conditions without difficulty and hardship.

   e. It is designed for construction in small fabricating shops; based on 1959 prices, it should cost about $1,500 for a single unit.

   f. It is adequately detailed in Y & D Drawing 813538 dated 1 September 1959 and sufficiently described in this report for preparation of procurement documents.

RECOMMENDATIONS

It is recommended that snow-leveling drags and snow-finishing drags be included in any equipment allowance for compacting snow where a Navy cold-processing technique is used for the construction effort.

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APPENDIX A

FIELD TESTS AND EVALUATION OF DRAGS FOR SNOW COMPACTION

APPENDIX A

FIELD TESTS AND EVALUATION OF DRAGS FOR SNOW COMPACTION

Following Operation Highjump to the antarctic in 1947, the Bureau of Yards and Docks established a research task to develop the techniques, materials and equipment necessary for building and maintaining high-strength, load-bearing snow. As various techniques and equipment were conceived, they were tested and evaluated in field trials. The first of these trials were conducted at Point Barrow, Alaska, during the winter of 1947-48. The equipment tested included the Canadian-type snow drag[2] and the pontoon drag (Figure 1) used at Highjump, a fixed-screed steel drag (Figure 13), and a modified sheepsfoot roller. Little other than the development of testing procedures was gained in these trials; however, these procedures were invaluable in the test and evaluation of drags and other snow-compaction equipment in subsequent trials.

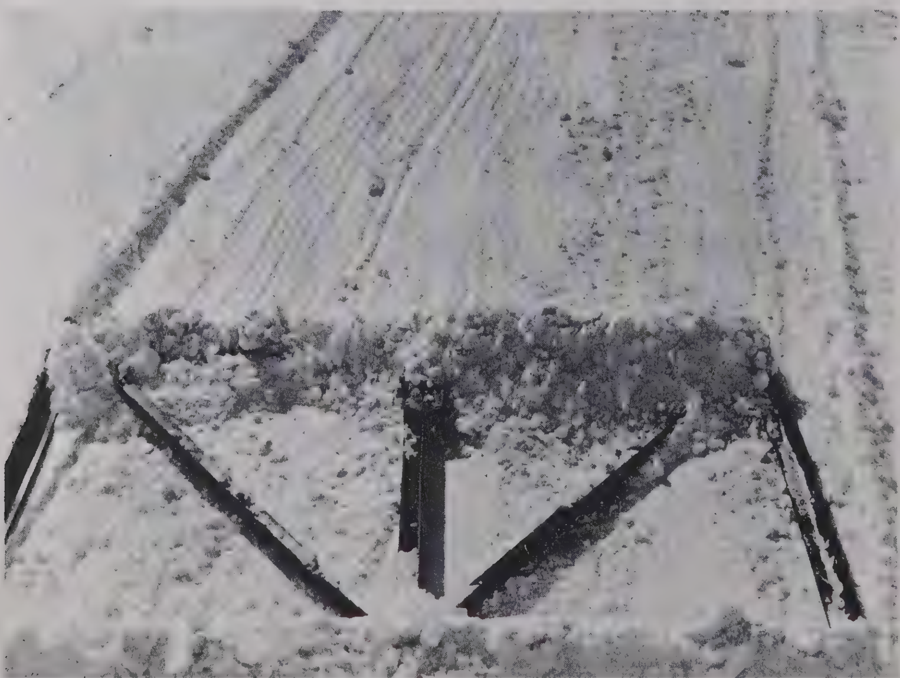

Figure 13. Testing the fixed-screed steel drag at Point Barrow in 1947-48.

Camp Hale (1949-50)

During the winter of 1949-50, the depth-processing technique of compacting snow was first tested by the Navy at Camp Hale, Colorado.[3] The basic pieces of equipment used in these tests, which were made on shallow snow, were a slightly modified commercial snow mixer and a large steel roller. Trucks were employed to test the compacted snow produced in these trials. The type of steel drag used at Point Barrow was replaced with a fixed-screed wooden leveling drag (Figure 2) fitted with metal cutting edges (Figure 4) on the front and rear screeds. The depth-processing technique showed much promise towards producing high-strength snow. The wooden drag was found to be very useful in spreading and leveling soft to medium-hard snow. Also, primary compaction of soft snow was obtained by dragging.

Point Barrow (1950-51)

During the winter of 1950-51, the Camp Hale equipment was used again in shallow snow tests at Point Barrow, Alaska.[4] In addition to the Camp Hale equipment, a simplified wooden drag and the type of pontoon drag used at Little America were tested and evaluated. The simplified wooden drag was not as effective as the Camp Hale wooden leveling drag, and it was eliminated as a piece of snow-compaction equipment. It was found also that the large steel roller was more effective than the pontoon drag as a compressive compactor. As a result, the pontoon drag was eliminated as a piece of compaction equipment.

Sierra Test Site (1951-52)

During the winter of 1951-52, two types of slightly modified snow mixers and several types and sizes of large steel rollers were tested on deep snow at the Sierra Test Site, Crestview, California.[5] Drags used in these tests included the wooden leveling drag (Figure 2), and adjustable-blade steel drag, and a toboggan-type drag. A fairly strong snow mat about 10 inches thick was produced on top of deep snow. This mat was successfully tested with tracked and wheeled construction equipment. It was found that the adjustable-blade steel drag was effective only in soft snow, and the toboggan drag was only slightly effective in older, harder snow. The metal-faced wooden drag was effective in spreading and leveling both soft and moderately hard snow, and it was somewhat effective in compacting shallow snow. As a result, all drags tested up to that time, except the metal-faced wooden drag, were eliminated as pieces of snow-compaction equipment.

Hard Top I and II (1953-54)

During 1953 and 1954, snow-compaction trials were conducted on the deep perennial snow of the Greenland Ice Cap in Operations Hard Top I and II.[6,7] Each year an emergency-sized compacted-snow runway was constructed by depth-processing the snow. After construction, the runways were tested with wheeled aircraft.

The compaction equipment for the 1953 trials included a modified soil preparer, or snow mixer, a large steel roller, and a wooden leveling drag. To construct the runway, it was necessary to use the drag for jobs other than that of leveling drift snow and spreading and leveling windrows (Figure 6) left by the snow mixer. First, it was used as a cutting drag to grade and level the sastrugi (Figure 14). Finally, to obtain a smooth, hard surface on the compacted mat, it was converted to a finishing drag (Figure 8). This was accomplished by welding half-sections of oil drums under the front and rear screeds of the drag (Figure 7).

A snowplane was developed for grading and leveling sastrugi in the 1954 trials. This eliminated the need for a cutting drag, but not for the leveling and finishing drags. They were both used in constructing and maintaining the 1954 runway, together with snow mixers, large steel rollers, a rubber-tired roller, and the snowplane.

Operation Deep Freeze (1955-57)

Both leveling and finishing drags were part of the Navy snow-compaction equipment included in the 1955 allowance for Operation Deep Freeze I to the antarctic. The wooden leveling drag (Figure 3) was identical to the one used at Hard Top, except that it was fitted with special pad eyes for three-gang towing. The finishing drag (Figure 9) was a prototype design based on the field-fabricated oil drum design used at Hard Top. The finishing drag also was fitted for three-gang towing, as shown in Figure 10.

A compacted-snow runway has not been built in the antarctic; however, both drags were used in the construction and maintenance of the skiway for aircraft at Little America V and in the maintenance of the sea ice runway at McMurdo Sound.[8] Both drags performed satisfactorily. The only difficulty experienced was occasional breaking of the chain bridles in temperatures below -50 F at McMurdo Sound.

Squaw Valley (1957-59)

Between 1957 and 1959, prototypes of both the leveling and finishing drags were used by the Laboratory in the Squaw Valley Trials near Truckee, California.[9,10] Here, snow roads and parking areas were built and tested with trucks, busses and automobiles. During construction, the leveling drag was used to spread and level

windrows left by the snowplane and the snow mixer. The finishing drag was used to produce a smooth surface on the compacted snow (Figure 13). For maintenance of bumpy, uneven surfaces, both drags were employed. First, the leveling drag was used to cut and level the surface and then the finishing drag was used to obtain a smooth finish. Both drags were used in a like manner to compressively compact light snowfalls. For moderate snowfalls, they were used in conjunction with the rollers to compact the snow.

Figure 14. Leveling sastrugi with a modified wooden leveling drag on the Greenland Ice Cap in 1953.

APPENDIX B

BEARING PRESSURE OF SNOW-FINISHING DRAG

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by J. E. Dykins and E. H. Moser, Jr.

In studies on compacting shallow snow in Russia during World War II, Kragelski[11] investigated the action of rollers. To determine the bearing pressure of a roller on snow, he developed the equation

$$Q = \frac{1}{2}\sqrt[3]{\frac{P^2 J}{R\ell^2}} \tag{1}$$

where: Q = bearing pressure

P = total weight of roller

J = coefficient of snow hardness

R = radius of curvature

ℓ = length of roller

Kragelski further determined that the bearing pressure and compacting action of drags with cylindrical working elements were similar to those of rollers. The equation shows that the average bearing pressure of a roller or a round-bottom drag increases with the weight of the unit and the hardness of the snow surface, and that it drecreases with an increase in the radius and length of the unit.

For numerical computations with Equation (1), it is necessary to know the coefficient of snow hardness, J, for various densities and temperatures in natural to highly compacted snow. Kragelski developed a few values for J using a pressure disc of 6 square centimeters in a temperature of -2 degrees centrigrade. Other than the limited values for J in kilograms per cubic centimeter developed in that study, no values for J under other conditions are known. Therefore, Equation (1) could not be used to determine the bearing pressure for the finishing drag under variable conditions of temperature and density.

In all Navy studies on compacted snow since 1952, the Rammsonde rod advanced by SIPRE[2] has been used to determine a hardness index R for both natural and compacted snow. While this index has no physical value, it does show the relative hardness of

snow not only at the surface but also in depth. Some work has been done to relate average hardness indexes of specific snow mats with known loadings, but to date, this work, like Kragelski's tests for J, is very limited. As a result, a reliable equation for the bearing pressure of the drag under variable snow conditions relative to hardness index R values could not be developed.

During the trials, values for R were observed for various depths of penetration of the skids into the snow surface. These were:

Hardness Index (top 6 in. of snow) (R)	Approx. Penetration of Skids (in.)
20 - 25	3
45 - 50	2
90 - 100	1
190 - 200	1/2
250 - 300	1/4

Bearing pressures for the drag were computed for various depths of penetration of each skid between 1/4 and 3 inches. In usage, it was observed that, except on extra hard snow (250R or greater), the rear skid penetration in most cases was about half that of the front skid. This was attributed to the initial action of the front skid and the compressibility of snow with an index hardness of 200R or less.

In calculating the bearing pressure of the skids, two assumptions were made (see Figure 15): (1) The specific pressure is constant over the entire contact area of the skid; (2) no contact is made with the snow surface to the rear of the vertical center line of the skid. Both assumptions make the calculated values conservative.

For snow with a hardness index between 250R and 300R, or where both skids were penetrating approximately a quarter of an inch into the surface, the following equation was used:

$$Q = \frac{P}{1/2\,(S) \times 2\,\ell} \qquad (2)$$

where: Q = bearing pressure

P = 2,830 lb, or the total weight of the drag (see Figure 16)

$1/2\ (S)$ = ϕr (see Figure 15) with ϕ (in radians) = $\arccos \frac{r-x}{r}$, r = 24-in. and x = 1/4-in. penetration

ℓ = 144 in., or the length of each skid

For snow with a hardness index of 200R or less, or where the rear skid was penetrating into the snow about half the depth of the front skid, the following equations were used:

$$Q = \frac{1/2\ (P)}{1/2\ (S) \times \ell} \qquad Q_1 = \frac{1/2\ (P)}{1/2\ (S_1) \times \ell} \qquad (3)\ (4)$$

where: Q = bearing pressure (front skid)
Q_1 = bearing pressure (rear skid)

$1/2\ (P)$ = 1,415 lb or the weight on one skid (see Figure 16)

$1/2\ (S)$ = ϕr (see Figure 15) with ϕ (in radians) = $\arccos \frac{r-x}{r}$, r = 24-in. and x = 3-in., 2-in., 1-in. and 1/2-in. penetrations

$1/2\ (S_1)$ = ϕr with ϕ (in radians) = $\arccos \frac{r-1/2(x)}{r}$, r = 24-in. and $1/2(x)$ = 1-1/2-in., 1-in., 1/2-in., and 1/4-in. penetrations

ℓ = 144 in., or the length of one skid

Using these equations, the following bearing pressures were obtained for selected depths of penetration of the front skid:

Penetration (in.)	Bearing Pressure Front Skid (psi)	Rear Skid (psi)
1/4	2.835	2.835
1/2	2.002	2.835
1	1.413	2.002
2	0.996	1.413
3	0.810	1.152

Except where the skid penetrates a quarter of an inch or less into the surface, the maximum bearing pressure occurs under the rear skid.

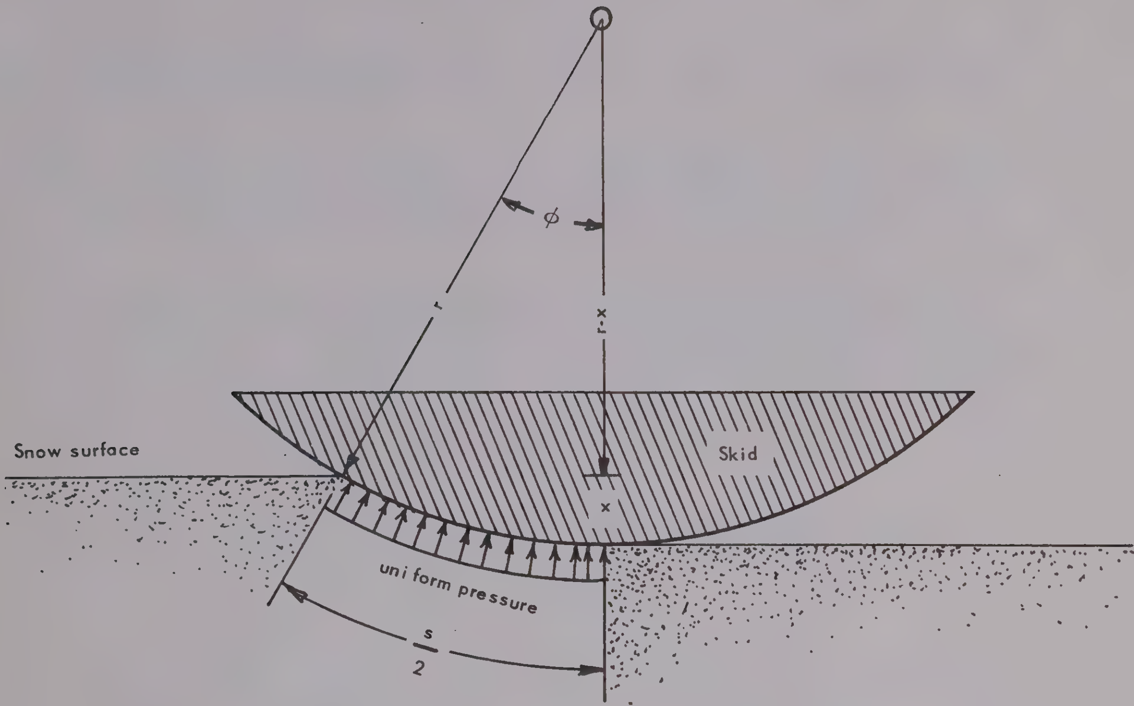

Figure 15. Diagram showing surface contact of front skid on finishing drag at x depth of penetration into snow surface.

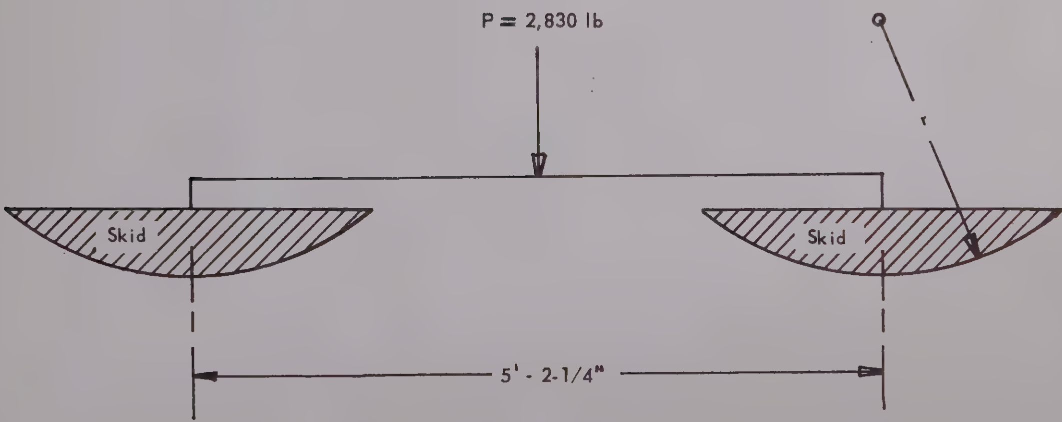

Figure 16. Diagram of snow-finishing drag. Radius, r, of each skid is 24 inches and length, ℓ, is 144 inches.

GLOSSARY

Compressive Compaction. Packing snow with rollers, drags or other equipment to increase its density and hardness.

Depth-Processing. Intermixing and packing a selected depth of snow to increase its load-bearing capacity. In the Navy technique, this is accomplished by a combination of passes with a snow mixer and a large-diameter roller.

Hardness Index. A relative index of hardness in snow obtained with a special cone-type penatrometer called a Rammsonde rod. High and low hardness numbers refer to hard and soft snow, respectively. All such numbers in NCEL reports are suffixed with the letter R, thus: 125R.

Lane. A single pass made by a piece of equipment.

Sastrugi. Wavelike ridges of snow formed by the wind on a level surface.

Snow Mat. An area of compacted snow of known depth.

Windrow. Spoil bank of snow deposited along the edge of equipment working in snow.

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